STUDY OF DARK MATTER INSPIRED cMSSM SCENARIOS AT A TeV-CLASS LINEAR COLLIDER

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1 Introduction

The connections between Cosmology and Particle Physics are receiving significant attention for sharpening the physics case for a Linear Collider (LC), operating at energies up to about 1 TeV. Not only the anticipated accuracy of the LC data appears best suited for a deeper understanding of the cryptic messages obtained by satellite experiments. Cosmology data also offer an important opportunity to re-consider the LC potential for new benchmark scenarios with well-defined requirements in terms of measurement accuracies, useful to optimize the detector design.

Within the constrained MSSM (cMSSM) parameter space, there are three regions, compatible with the LEP-2 constraints, where the lightest neutralino, χ, provides a cold dark matter density $\Omega_{CDM}h^2$ matching the WMAP results. These are i) the co-annihilation ($\chi\tilde{\ell}$) region at small slepton-χ mass difference, the rapid annihilation ($\chi\chi \to A$) region at large values of $\tan\beta$ and the focus point region. Assessing the LC potential in testing the nature of dark matter requires to determine its reach and accuracy along these regions, while varying the reduced set of free parameters ($m_{1/2}$, m_0, $\tan\beta$, A_0) and study the experimental implications. The accuracy of the WMAP data reduces the dimensionality of the cMSSM parameter space, introducing relations between m_0 and $m_{1/2}$, for each value of $\tan\beta$, which will be referred to as WMAP-lines [1].

This study represents a preliminary survey of the capabilities and experimental issues for slepton and Higgs analyses of benchmarks situated along the co-annihilation region and in the rapid annihilation funnel. It considers centre-of-mass energies, $\sqrt{s}$, of 0.5 TeV and 1 TeV. Events have been generated with `Pythia 6.205`+`Isajet 7.67`, including bremsstrahlung effects, full detector simulation has been performed with the `Brahms` program and fast simulation with a modified version of `Simdet 4.0` and the `JAS-3` LCD software.

2 Slepton Reconstruction in co-Annihilation Tail

The co-annihilation tail, at moderate $\tan\beta$ values, runs along the lower edge of the allowed cMSSM parameter space, up to $m_{1/2}$ values of $\simeq 900$ GeV. At the LC, the highest reach in $m_{1/2}$ comes from right-handed slepton pair production, $e^+e^- \rightarrow \tilde{\ell}^+_R\tilde{\ell}^-_R$. At 1 TeV, the LC sensitivity extends up to the extreme tip of the co-annihilation tail for $\tan\beta$ = 5 - 10, also beyond the LHC reach for sleptons, which stops at $m_{1/2} \simeq 500$ GeV. Along the WMAP line, $\tilde{\ell}_R$ becomes nearly degenerate with *chi*, resulting in soft leptons production. Tuning $\sqrt{s}$, to maximize the production cross section σ, further softens the lower lepton energy endpoint, $E^{min}_{\ell} = \frac{1}{2}M_{\tilde{\ell}}\left(1 - \frac{M^2_{\tilde{\chi}^0_1}}{M^2_{\tilde{\ell}}}\right)\gamma(1 - \sqrt{1 - \frac{M^2_{\ell}}{E^2_{beam}}})$. At $\tan\beta$=5, 10 E^{min}_{ℓ} is as low as 1.5 GeV and 4 GeV respectively. In these scenarios, lepton identification becomes critical due to the intrinsic momentum cut-off of the ECAL and muon chambers and to the $\gamma\gamma \rightarrow$ hadrons background. In the Tesla detector design with B=4 T, the lower momentum cutoffs are 1.5 GeV and 4.2 GeV respectively. The process $e^+e^- \rightarrow \tilde{\ell}^+_R\tilde{\ell}^-_R \rightarrow \ell^+\chi^0_1\ell^-\chi^0_1$ has been studied at 1 TeV for $m_{1/2}$= 600 GeV, 800 GeV and 950 GeV with $\tan\beta$=5. The momentum acceptance for lepton identification cuts into the lower momentum endpoint for $m_{1/2} \geq 600$ GeV, thus making difficult the extraction of the slepton-χ mass difference from the lepton momentum spectrum. This problem can be mitigated by using the specific ionization, $\frac{dE}{dx}$ in the Time Projection Chamber, to identify low momentum electrons. Assuming 200 samplings and 4.5 % resolution, the $\frac{dE}{dx}$ provides $\geq 4\sigma$ e/π separation for $p > 0.9$ GeV. This recovers the accessibility of the lower energy endpoint for selectrons, and thus the $\tilde{e}$-χ mass difference. A fit to the reconstructed energy spectrum, using the full `Geant-3` simulation, shows that the mass difference can be measured with a statistical accuracy of 0.02 % to 0.03 % for 600 GeV $< m_{1/2} <$ 950 GeV.

3 χ and A^0 Reconstruction in Rapid Annihilation Funnel

In the rapid annihilation funnel, the dark matter density $\Omega_{CDM}h^2$ is controlled by the value of $R = 2M_\chi/M_A$ and $\tan\beta$. A scan of m_0, $m_{1/2}$, $\tan\beta$, performed with `microMEGAS`[3], imposing $M_{h^0} > 112$ GeV and $0.093 < \Omega_{CDM}h^2 < 0.129$, shows that the derivative $\delta\Omega_{CDM}/\delta R$ is 2-5, depending on the exact position and the value of $\tan\beta$. Similar results have been obtained using `DarkSUSY`[2]. This indicates that the ratio of the χ to A^0 boson masses must be measured to better than 1 % for predicting $\Omega_{CDM}h^2$ to an accuracy comparable to that expected by the next generation of satellite experiments. It is interesting to observe that, in the cosmologically favored funnel region, all the Higgs bosons are

within the LHC sensitivity[4]. However, the LHC accuracy on M_{A^0} critically depends on the availability of the $A^0 \to \mu^+\mu^-$ channel. This will be at the borderline of the LHC sensitivity for a significant part of CDM-favored region. Therefore, it is important to assess the LC potential in studying the $e^+e^- \to H^0A^0$ channel[5]. A study point has been defined, corresponding to m_0=380.00 GeV, $m_{1/2}$=420.00 GeV, $\tan\beta$=53, A=0, $Sgn(\mu)$=+1 and M_{top}=178 GeV. These parameters give M_{A^0}=419 GeV, $M_{\chi_1^0}$=169 GeV and $M_{\tilde{\tau}_1}$=195 GeV. The analysis strategy at the LC is to determine first $M_{\tilde{\tau}_1}$ by threshold scan. A two-point scan at $\sqrt{s}$ values of 425 GeV and 500 GeV with 200 fb^{-1} and 300 fb^{-1} respectively, will provide an accuracy $\delta M_{\tilde{\tau}_1}/M_{\tilde{\tau}_1} \simeq 0.5$ %. Then M_χ can be extracted from the $\Delta M = M_{\tilde{\tau}_1} - M_\chi$ mass difference using the $\tilde{\tau}_1 \to \tau\chi$ jet kinematics, at $\sqrt{s}$=0.5 TeV. The estimated accuracy is $\delta M_\chi/M_\chi \simeq 0.8$ % for 500 fb^{-1} of data. At 1 TeV, the effective $e^+e^- \to H^0A^0 \to b\bar{b}b\bar{b}$ production cross section

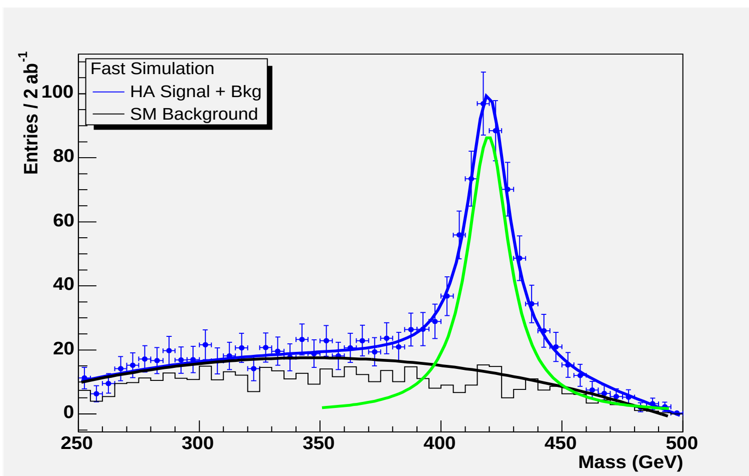

Figure 1: Di-jet mass distribution for the H^0A^0 analysis. The histograms show the reconstruction results for the signal+background and the background alone and the curves the results of the 5-parameter fit.

for the chosen benchmark point is 0.9 fb and the final state can be separated from both the Z^0Z^0, W^+W^- and the inclusive $b\bar{b}b\bar{b}$ backgrounds. After event selection, the di-jet pairing which minimizes the di-jet mass difference has been chosen and the di-jet mass resolution improved by applying a 4-C fit. The resulting mass distribution is shown in Figure 1. The A^0 mass, M_A, and width, Γ_A have been extracted by a multi-parameter fit leaving the parameters of the Breit-Wigner signal and second-order polynomial background free. The

fit has been repeated by including also the $M_A - M_H$ mass splitting, or by constraining it to the model value. Results are summarized in Table 1.

	6-par Fit	5-par Fit
M_A (GeV)	$415.9^{+2.5}_{-1.4}$	418.9±0.8
Γ_A (GeV)	11.5±4.8	16.1±2.7
$M_H - M_A$ (GeV)	$8.5^{+2.3}_{-5.2}$	1.4 (Fixed)

Table 1: Results of the fit for 2 ab^{-1} of data at 1 TeV

4 Ω_{CDM} Predictions from the LC Data

In this study, the accuracy corresponding to the LC data precision has been evaluated, within the cMSSM, for the fast annihilation funnel benchmark point. First the dependencies of $\Omega_{CDM}h^2$ on SUSY and SM parameters have been

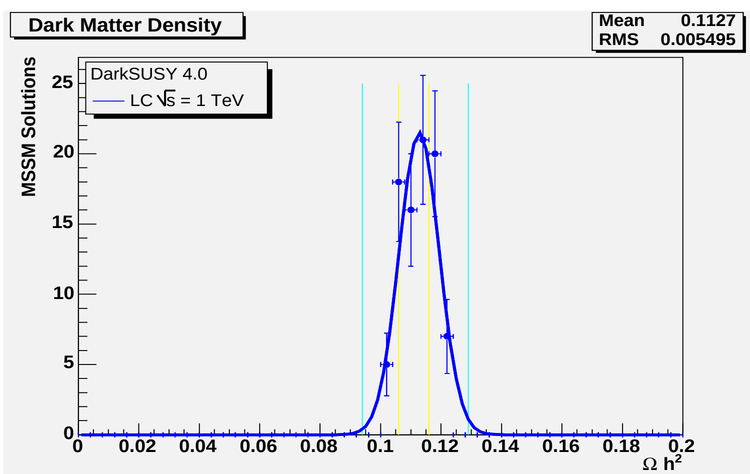

Figure 2: Probability density function of $\Omega_{CDM}h^2$ for the cMSSM solutions compatible with the LC measurements of M_A, M_χ and $M_{\tilde{\tau}_1}$. The vertical lines show the uncertainty of the WMAP result (light blue) and that expected by PLANCK (yellow).

evaluated. Then a scan of the cMSSM parameter space has been performed using `DarkSUSY 4.0`. The constraints of the masses obtained in the previous section have been included together with $\tan\beta \pm 3$, $M_{top} \pm 0.1$ GeV and $M_b \pm 0.05$ GeV. Large SUSY corrections to Γ_A also affect the computations

of $\Omega_{CDM}h^2$. These can be controlled both by the direct determination of the A^0 boson width and by that of the $h^0 \to b\bar{b}$ branching fraction. In fact $\mathrm{BR}(h^0 \to b\bar{b})$ is sensitive to the same Δm_b shift of the b-Yukawa coupling, due to SUSY loops, responsible for the corrections to Γ_{A^0}. The precision of the LC data can control the A^0 width to 10 % by relating $\mathrm{BR}(h^0 \to b\bar{b})$ to Γ_{A^0} as: $\Gamma_{A^0} = \frac{\mathrm{BR}(h^0 \to b\bar{b})}{\mathrm{BR}(A^0 \to b\bar{b})} \times \Gamma_{h^0} \times \tan^2\beta$. A direct scan at a $\gamma\gamma$ collider may improve this accuracy. The resulting p.d.f. for $\Omega_{CDM}h^2$ is shown in Figure 2. The relative accuracy is $\frac{\delta\Omega h^2}{\Omega h^2} = \pm 0.049$ (SUSY Masses) $\pm$ 0.050 (SUSY Corr.) $\pm$ 0.035 (M_{quarks}).

5 Conclusion

The accuracy in the measurement of the masses of sleptons and heavy Higgs bosons in cMSSM scenarios compatible with the WMAP results on cold dark matter, has been re-analyzed in view of the requirements for predicting Ωh^2 to a few % from SUSY measurements. Results show that the typical $\mathcal{O}(0.1~\%)$ accuracy on slepton masses is realisable along the co-annihilation tail. At small $M_{\tilde{\ell}} - M_{\chi_1^0}$ values, this region is characterized by momenta of the emitted leptons which require to extend the acceptance of lepton identification and a careful study of the $\gamma\gamma$ background rejection. The A funnel region presents an interesting analysis program at 0.5 TeV and 1.0 TeV, where large data sets should provide a $\Omega_{CDM}h^2$ accuracy of $\mathcal{O}(5~\%)$ and control of systematics to a comparable level.

References

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